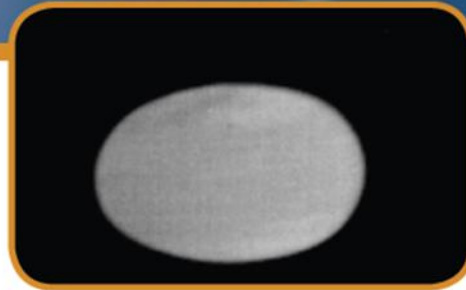
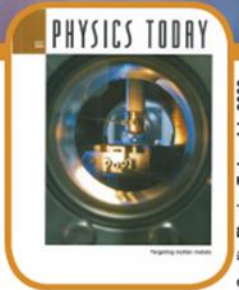
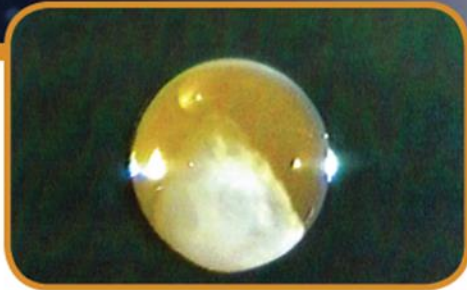


Marshall Space Flight Center Electrostatic Levitation Laboratory



Effects of Oxygen Partial Pressure on the Surface Tension of Liquid Nickel

Michael P. SanSoucie

Jan R. Rogers

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Vijaya Kumar

Justin Rodriguez

Xiao Xiao

Douglas M. Matson

Tufts University, Medford, MA

Nineteenth Symposium on Thermophysical Properties
Boulder, CO
June 21-26, 2015

MSFC Electrostatic Levitation (ESL) Laboratory



Glenn working on the ESL Lab's Main Chamber

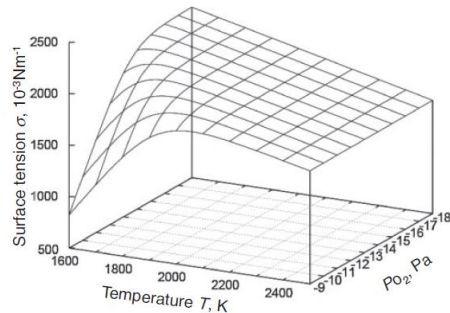
- Michael SanSoucie (EM50)
- Jan Rogers (EM50)
- Paul Craven (EM50)
- Trudy Allen (METTS)
- Glenn Fountain (ESSSA)
- Curtis Bahr (ESSSA)

Tufts University, Dr. Matson's Group

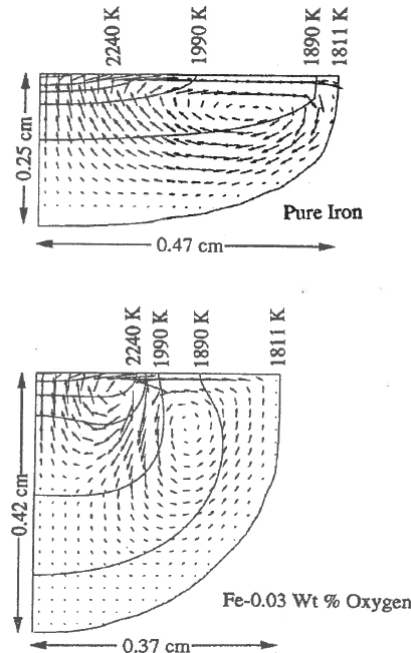


- Left to Right:
- Francesca Minervini
 - Xiao Xiao
 - Vijaya Kumar
 - Erick Garcia
 - Vadim Reytblat
 - Nina Dytiuk
 - Justin Rodriguez
 - Gabrielle String
 - Douglas Matson

Need for Oxygen Partial Pressure Control



Measured relationship between surface tension, temperature, and p_{O_2} for molten iron¹



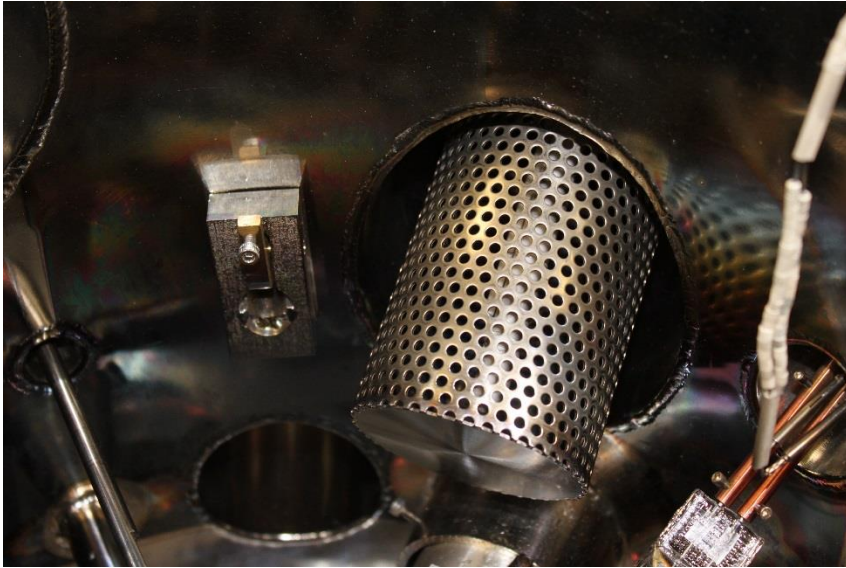
Calculated velocity and temperature fields for gas tungsten arc welding of pure iron and iron with 0.03 wt% oxygen²

- Supports microgravity principal investigators
 - An oxygen control system is planned for the European Space Agency (ESA) Materials Science Laboratory Electromagnetic Levitator (MSL – EML) on the International Space Station (ISS)
 - Japan Aerospace Exploration Agency (JAXA) Electrostatic Levitation Furnace (ELF) that is planned to fly on the ISS
- Surface tension of molten metals is affected by even a small amount of adsorption of oxygen
 - Oxidation may have an impact of 10-30% on surface tension measurements³.
 - Causes a decrease in surface tension
- Oxidation can occur at very low p_{O_2}
 - Has been observed in the MSFC ESL as low as $\sim 1 \times 10^{-25}$ bar p_{O_2}

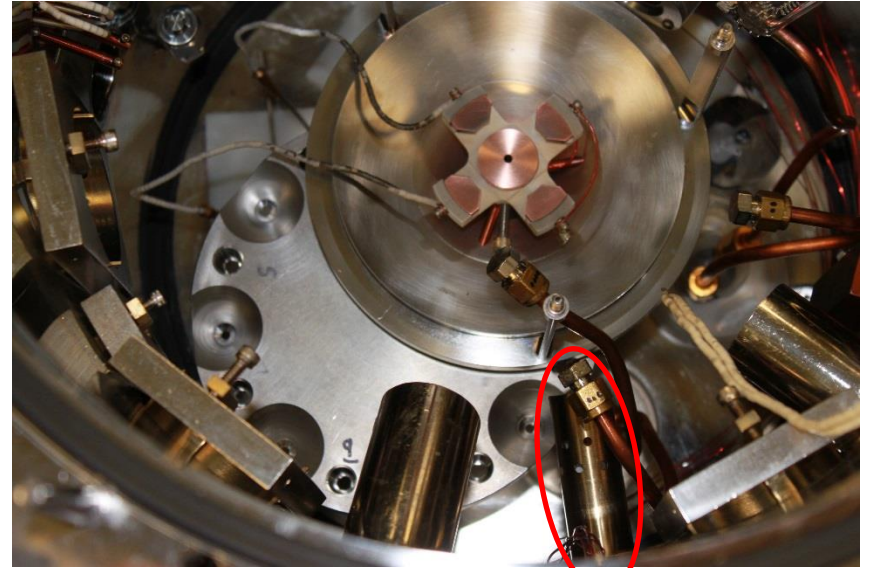
References:

1. Ozawa, S., et.al., *Relationship of Surface Tension, Oxygen Partial Pressure, and Temperature for Molten Iron*, Japanese Journal of Applied Physics, 2011, 50, p. 11RD05
2. DebRoy, T. and S.A. David, *Physical processes in fusion welding*, Reviews of Modern Physics, 1995, 67(1), p. 85-112
3. Ozawa, S., et. al. , *Influence of oxygen partial pressure on surface tension and its temperature coefficient of molten iron*, Journal of Applied Physics, 2011, 109.

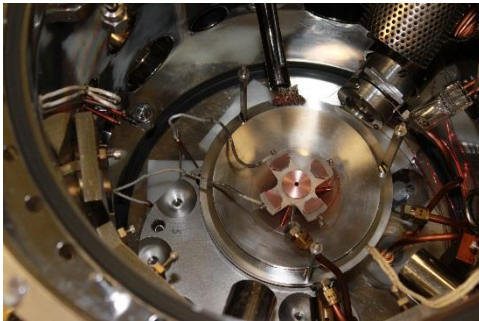
Hardware



Oxygen Pump



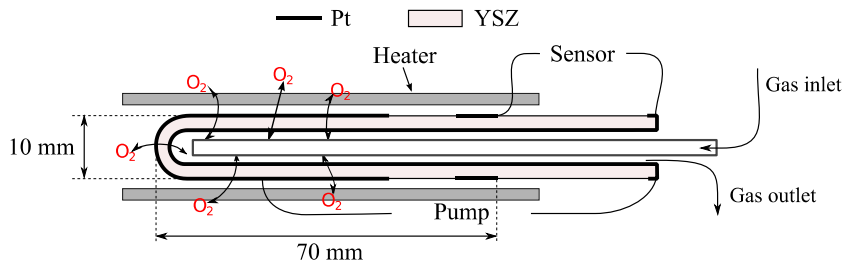
Oxygen Sensor



Controller

- Developed by Astrium North America
- Fabricated by Clausthal University of Technology (TU Clausthal)

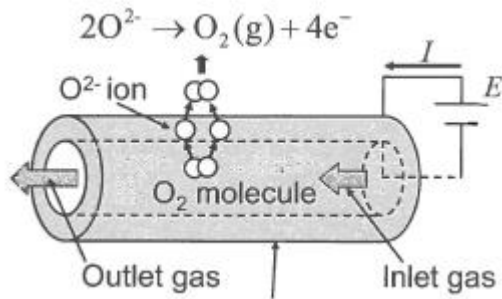
Oxygen Sensing



Ref: Schulz, M., et al., *Oxygen partial pressure control for microgravity experiments*, Solid State Ionics, 2012, 225, p. 332-336.

- Potentiometric sensor
 - Determines the difference in oxygen activity in 2 gas compartments separated by an electrolyte
 - Yttria-stabilized zirconia (YSZ)
- Activity of gaseous compounds corresponds closely with their partial pressures
- The cell generates an electromotive force
 - Difference in p_{O_2} between the process gas and air, which is the reference gas
- p_{O_2} is calculated by using the Nernst equation
 - $E = \frac{RT}{4F} \ln \left(\frac{p_{O_2}}{p_{O_2}^{ref}} \right)$
 - E is the electromotive force
 - R is the universal gas constant
 - F is the Faraday constant
 - $p_{O_2}^{ref}$ is the oxygen partial pressure of the reference gas (the lab atmosphere, in this case)
 - p_{O_2} is the oxygen partial pressure of the gas in question

Oxygen Pumping



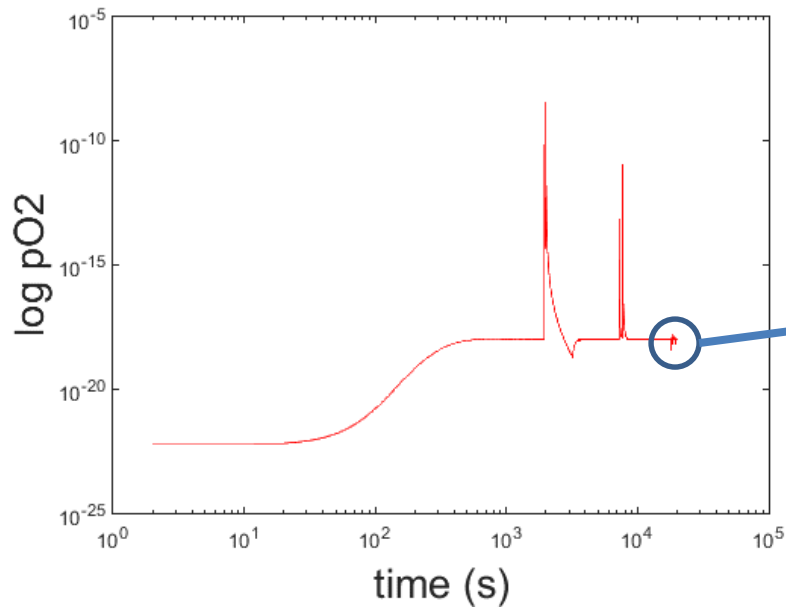
Schematic of oxygen ion pump

Oxygen molecules move through the YSZ tube from inside to outside when a difference in electrical potential is provided between the tube walls.

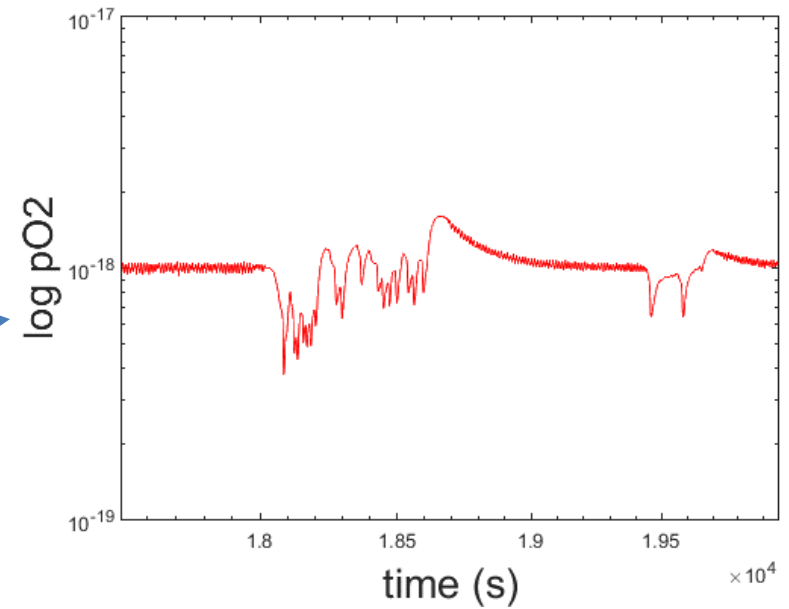
- Electric current is applied to the electrodes (Pt)
 - Charge moved across the electrolyte in the form of oxygen ions, O^{2-}
- Negative electrode
 - Oxygen is incorporated into vacancies of the electrolyte, V_{O}^{OO}
- Positive electrode
 - Oxygen leaves crystal lattice to form gaseous oxygen
- Must be operated above 500°C to enable sufficient ionic conductivity

Example of p_{O_2} vs. time

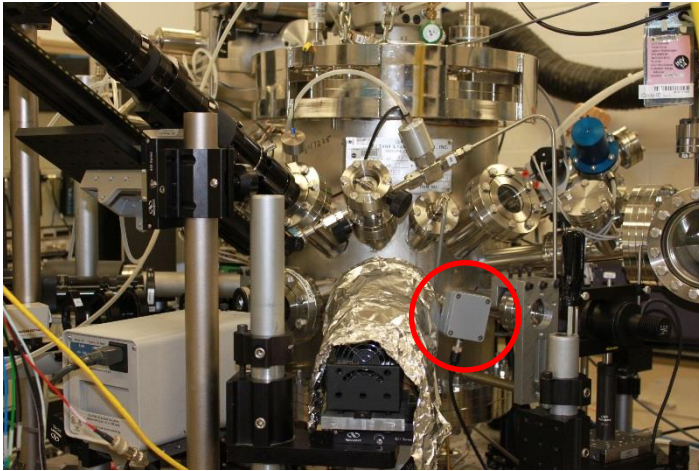
Oxygen partial pressure vs time



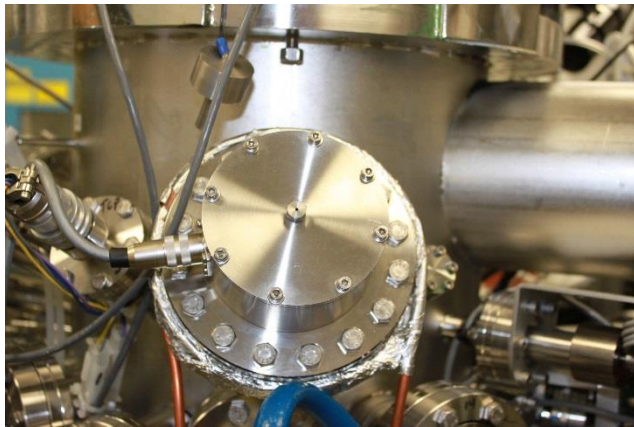
Oxygen partial pressure during sample processing



Results



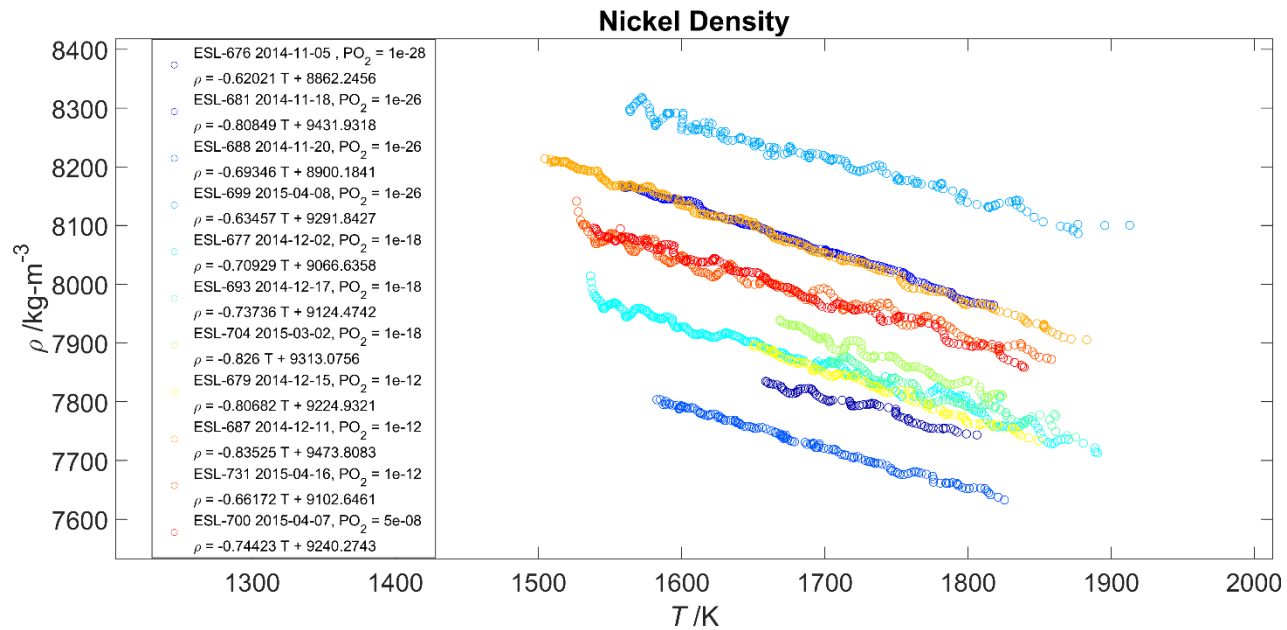
Oxygen Sensor



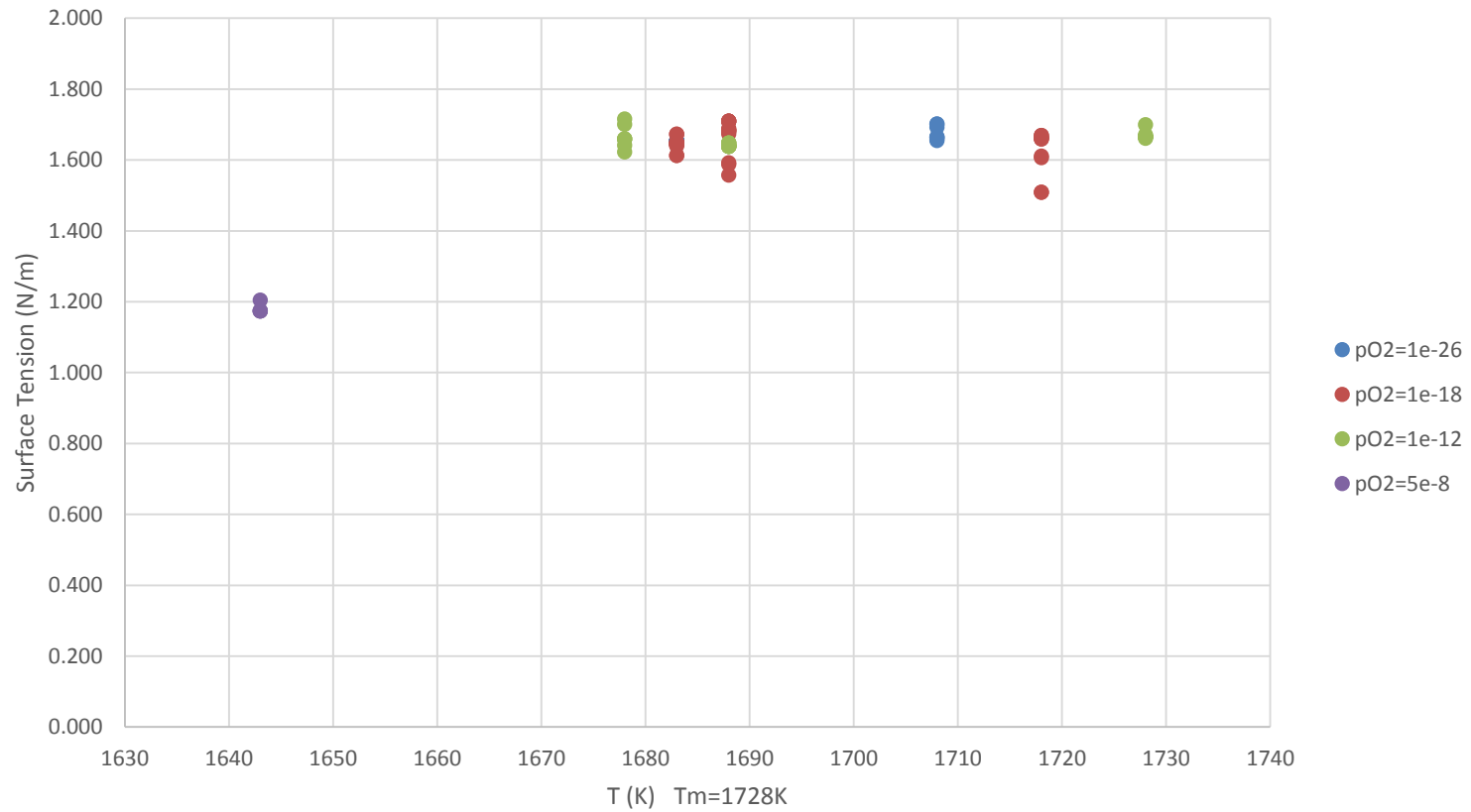
Oxygen Pump

- Nickel samples were arc melted at MSFC
- Processed in the electrostatic levitator at MSFC
- Data was analyzed by Tufts University
 - Density
 - Surface Tension
 - Viscosity
- Chemical Analysis
 - Done by Luvak Laboratories, Inc. (MA)

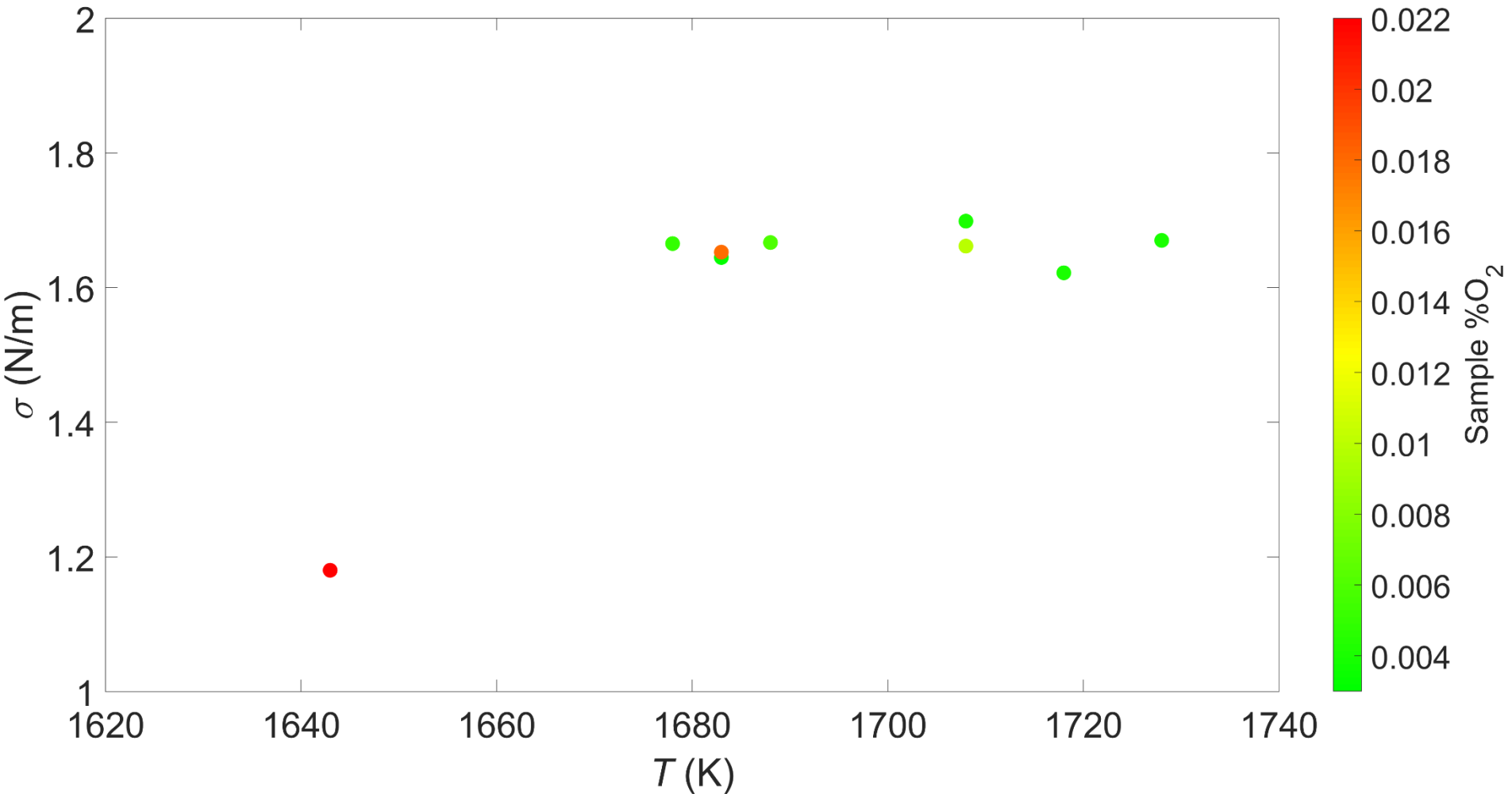
Density



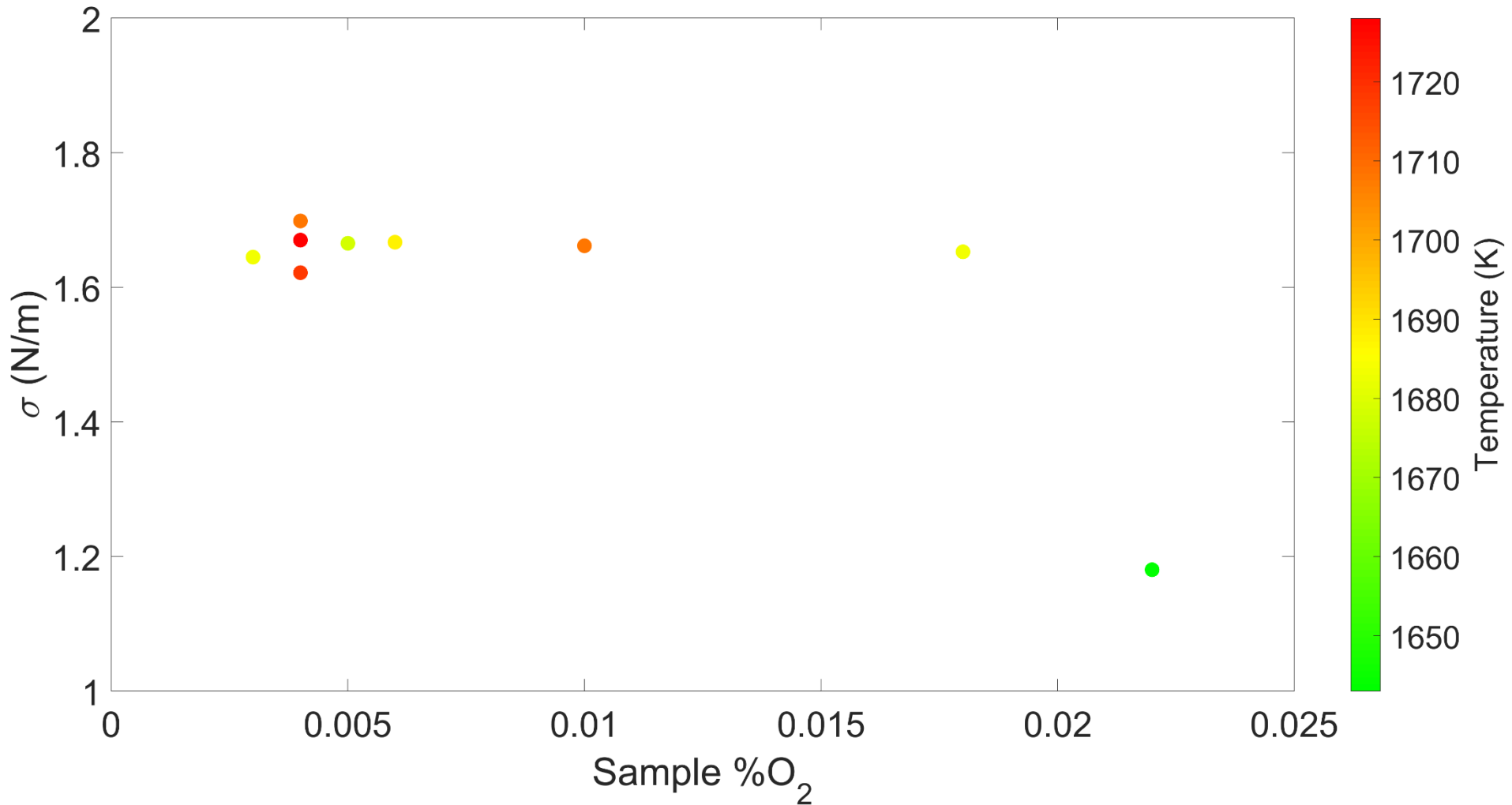
Surface Tension



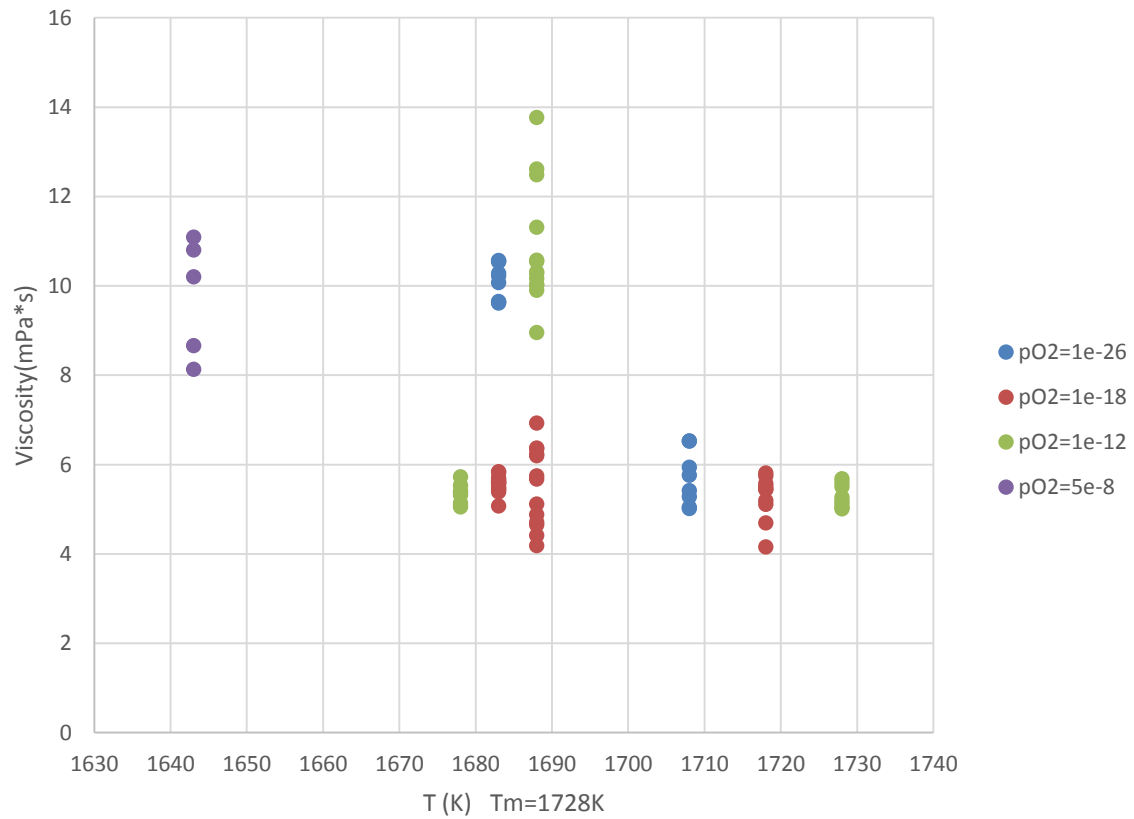
Surface Tension



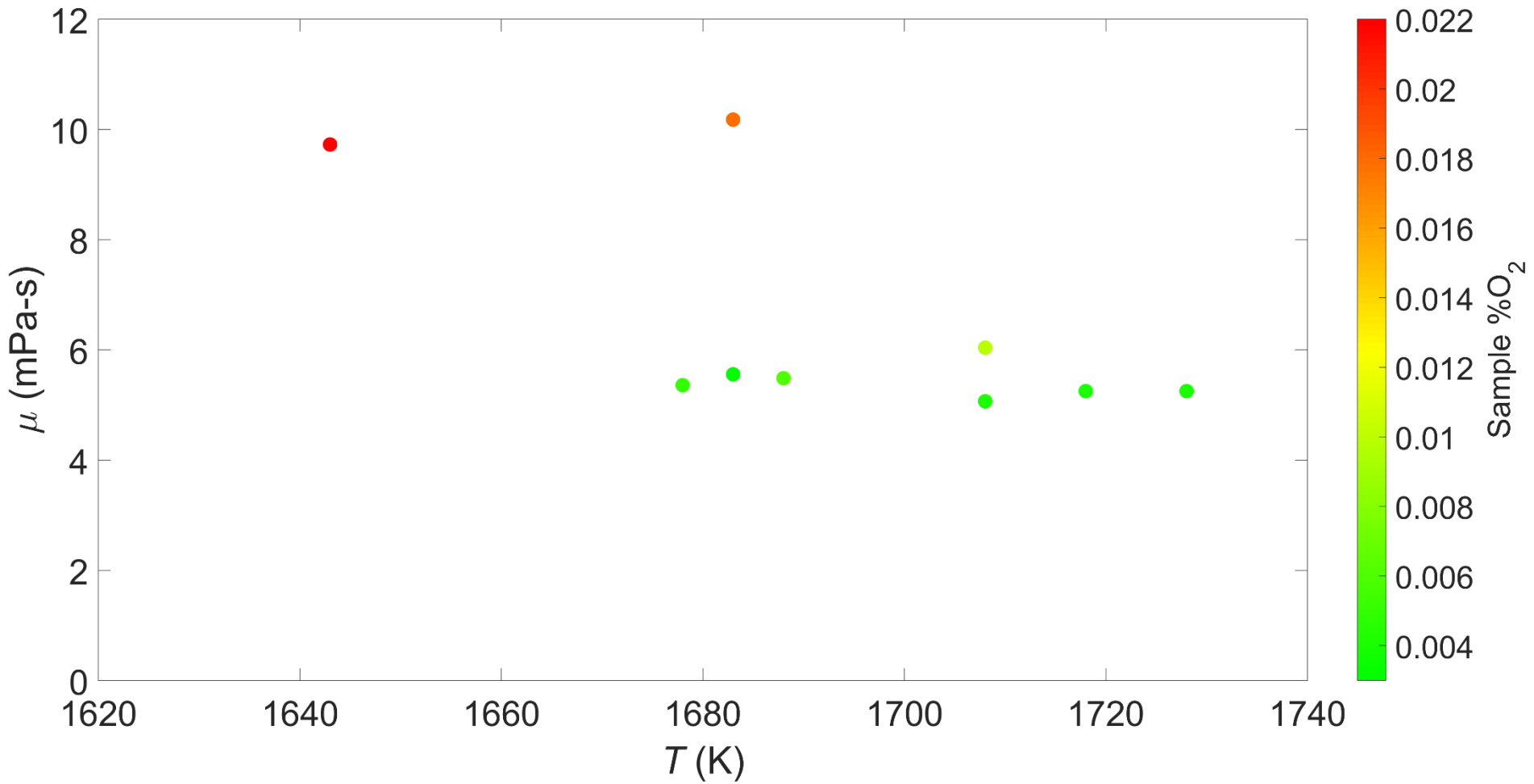
Surface Tension



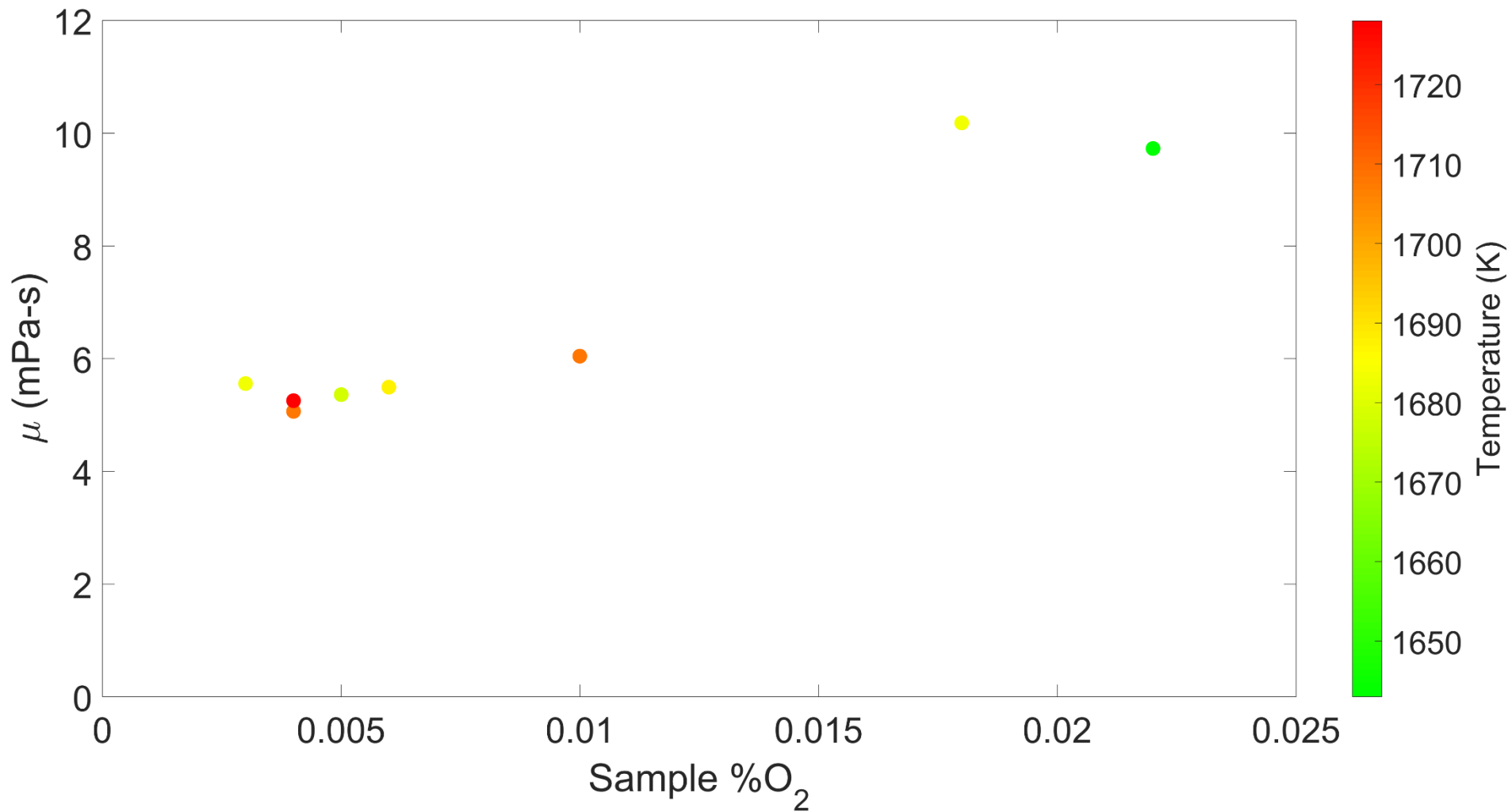
Viscosity



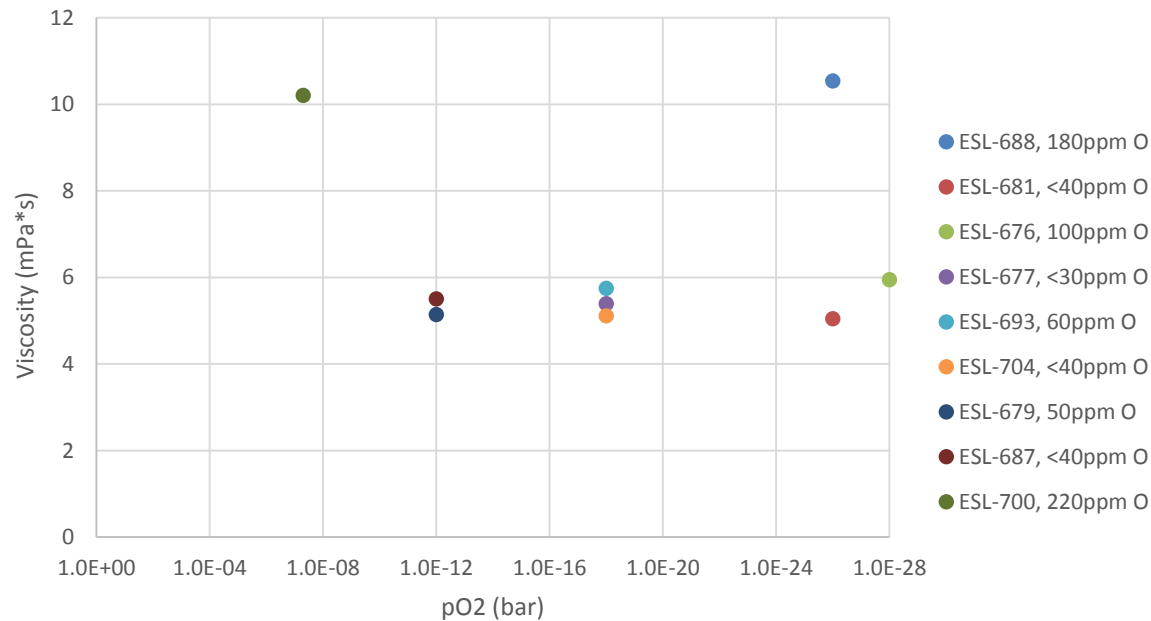
Viscosity



Viscosity



Oxygen Absorbed



- No correlation of oxygen absorbed with p_{O_2}
- Samples were not yet internally equilibrated
- More work to be done

Conclusions

- Little effect on surface tension
 - Need higher p_{O_2} levels
- The analysis showed the samples were not yet internally equilibrated
- The technique needs to evolve to include a thermal hold to equilibrate internal and external concentrations

Questions

